

X-38 SEAL DEVELOPMENT

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X-38 Seal Development

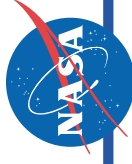
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NASA Glenn Research Center
October 25-26, 2000

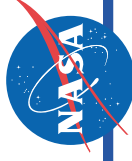
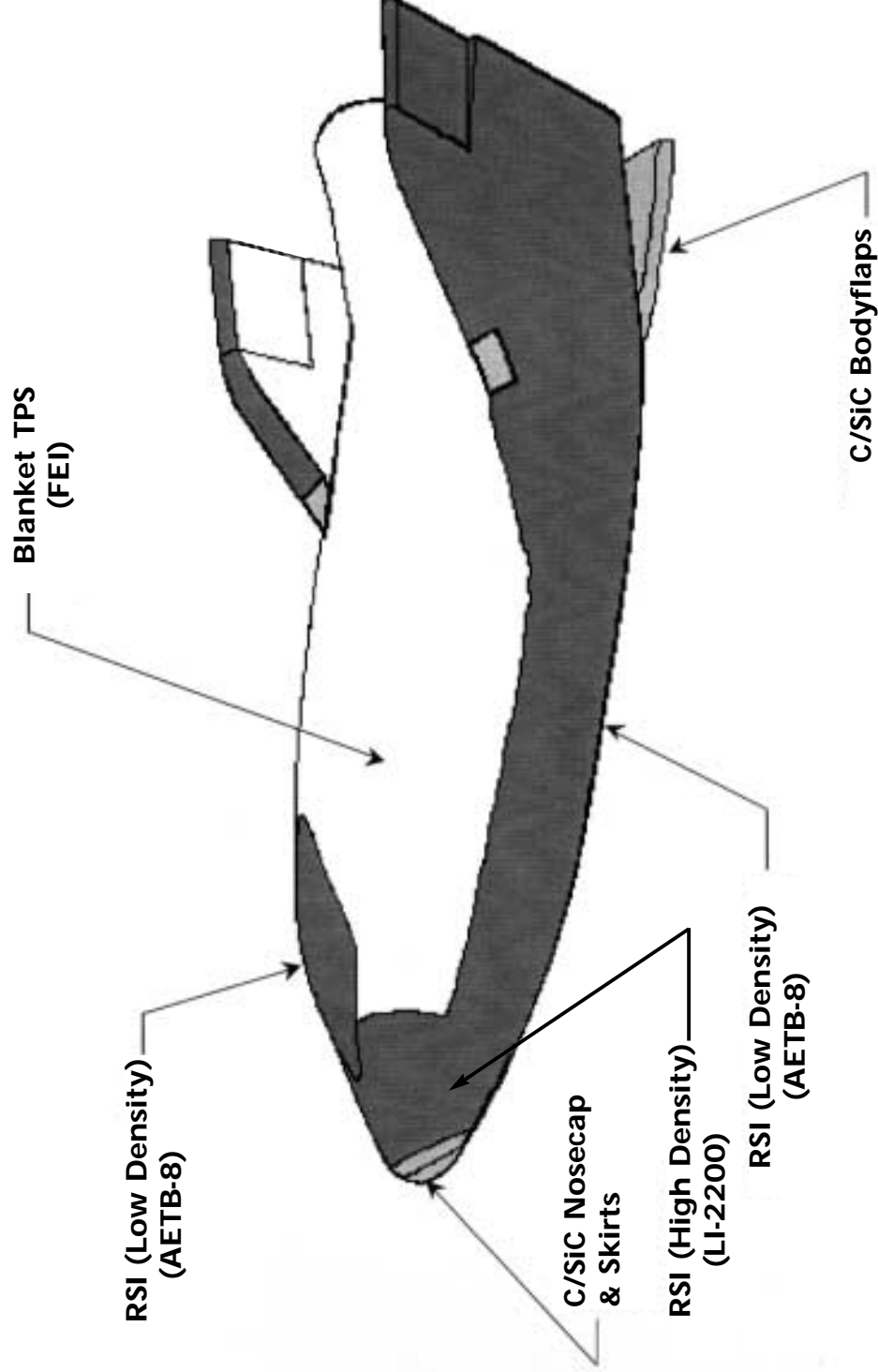


X-38 - Crew Return Vehicle

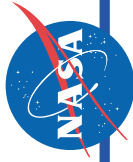
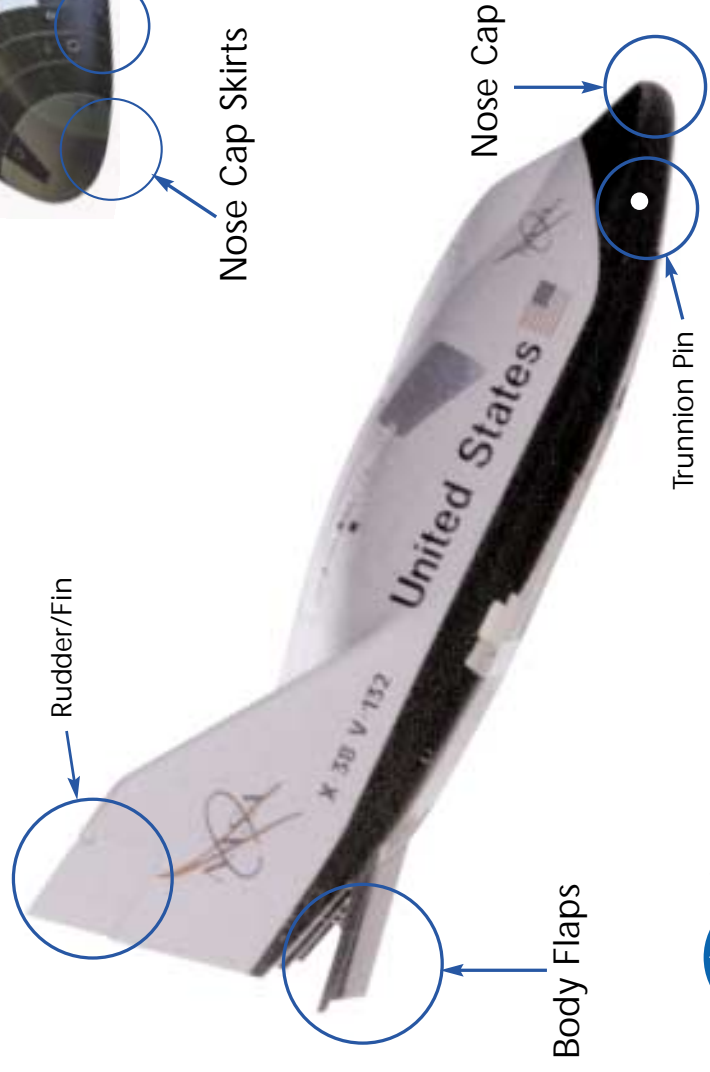
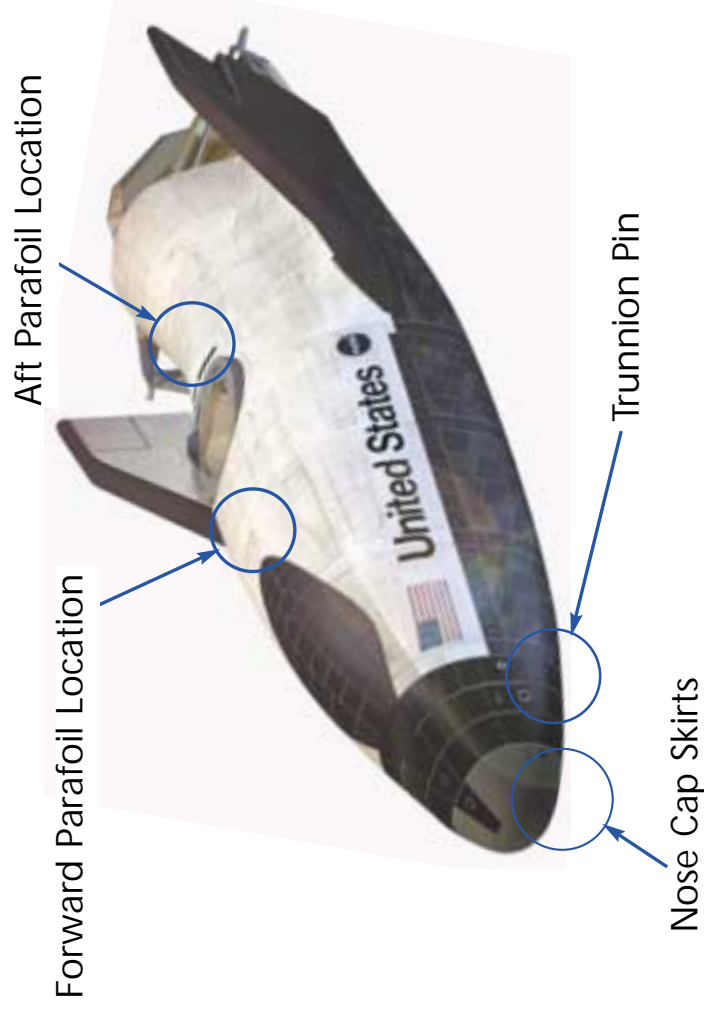
- ❖ An element of the International Space Station (ISS)
- ❖ Three Scenarios
 - ISS castastrophe
 - Emergency medical evacuation
 - Period of Space Shuttle unavailability
- ❖ X-38 Program Purpose:
 - To greatly reduce the costs and schedule for the development of crew Return Vehicles (CRVs) and Crew Transfer Vehicles (CTVs) through the use of the rapid development methodology associated with an X-project
 - Ground Testing
 - Atmospheric Testing
 - Space Flight Testing
- ❖ X-38 Major Milestones
 - Static Test-02/01
 - Primary Structure Completed
 - Vibro/Acoustic Test-11/01
 - TPS Installed
 - V-201 Delivery to KSC-03/02
 - First Flight-STS-114-07/02



X-38 TPS Configuration



X-38 Seal Locations



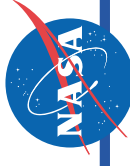
X-38 – TPS Seals

General Seal Requirements

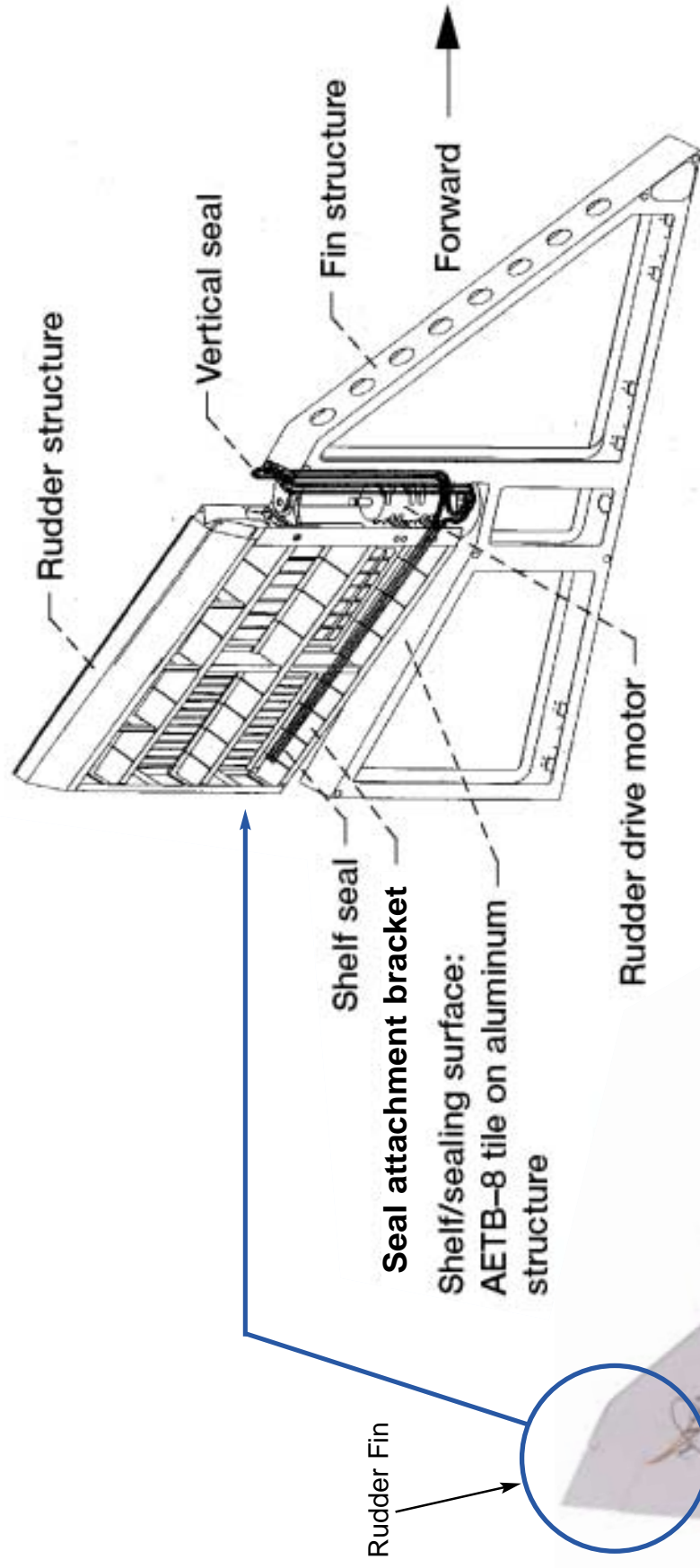
- 1) Single Flight Capability
- 2) High Temperature, Oxidative Environment
- 3) Combined Convective and Radiation Heating
- 4) Different Thermal Expansion of Seal Parts
- 5) Mechanical Load Plus Vibration/Acoustic Loads
- 6) Component Movement and Rotation
- 7) Wear Resistant
- 8) Low Pressure Environment (at Peak Heating)
- 9) Low Permeability to Minimize Leakage

X-38 Design Considerations

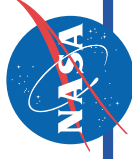
- 1) Use a Seal with Flight Heritage (Orbiter)
- 2) Operational Temperature – 1500-3000°F
- 3) Permeability – 1×10^{-10} - 1×10^{-11} Sq. M
- 4) Coefficient of Friction – 1.09-1.17
- 5) Installation Force Limit of 3 lb/in (Installed with 20-30% Seal Deflection)
- 6) Differential Pressures of 350-450 PSF During Peak Heating



X-38 Rudder/Fin Seal Assembly

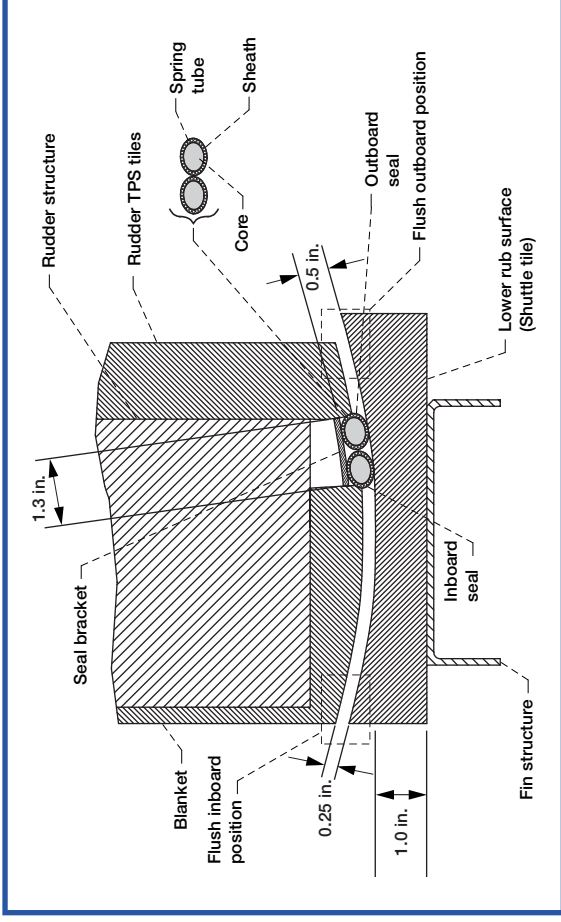


Rudder Fin



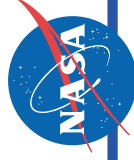
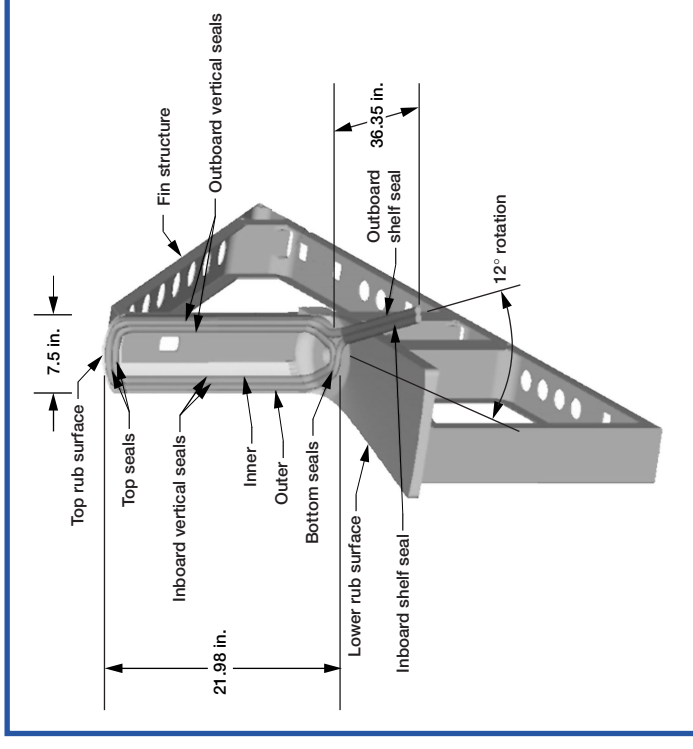
Baseline X-38 Rudder/Fin Seal Design

Cross Section of Rudder/Fin Seal Shelf Location

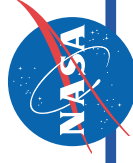
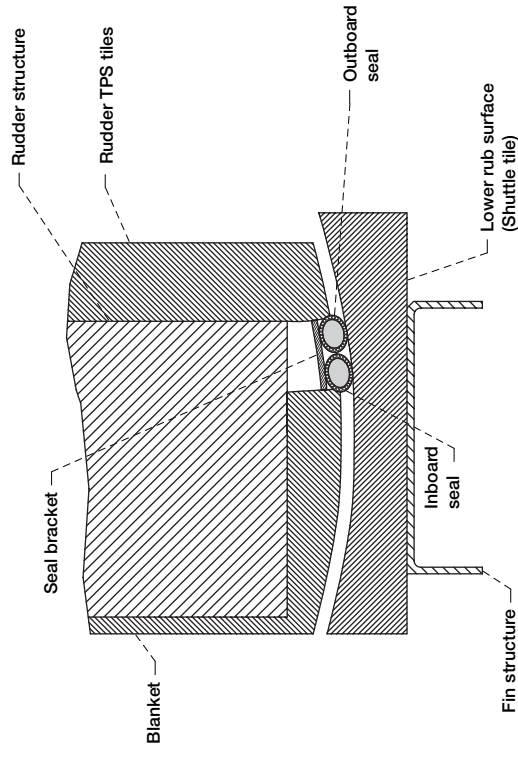
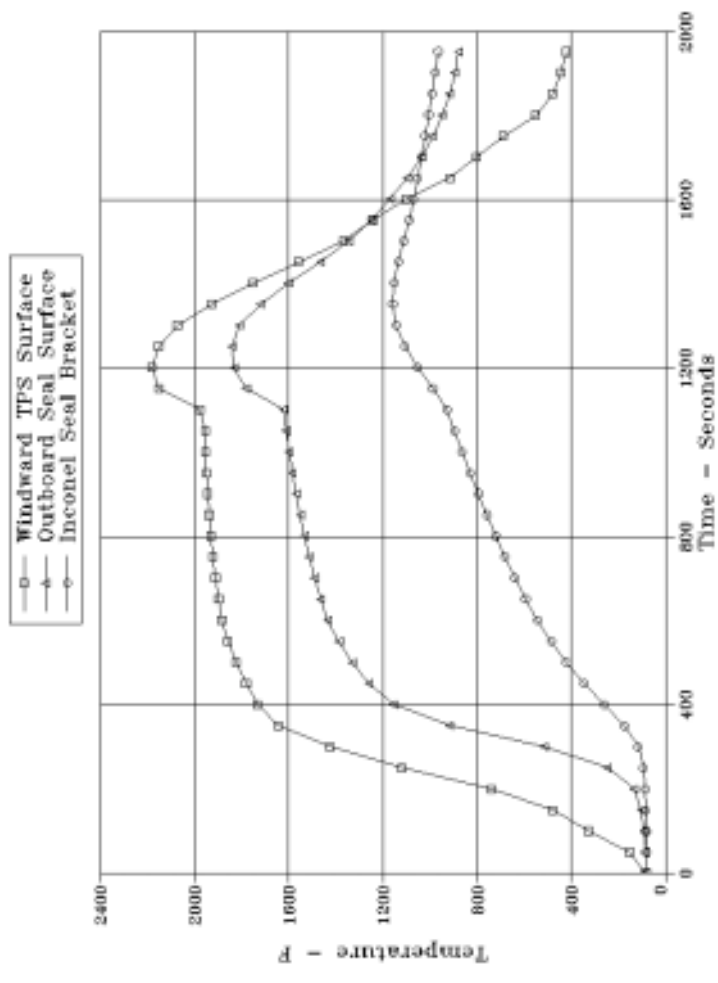


Rudder Shown at Flush Inboard Position

- ❖ Main Seal Components
 - Core: 6 pcf Saffil Insulation
 - Spring Tube: Inconel X-750
 - Sheath: Two Layers of Nextel 312 Fabric
- ❖ Nominal 20% Compression and 0.25-in. Gap



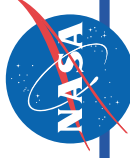
Rudder/Fin Hinge Line Thermal Response



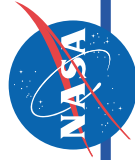
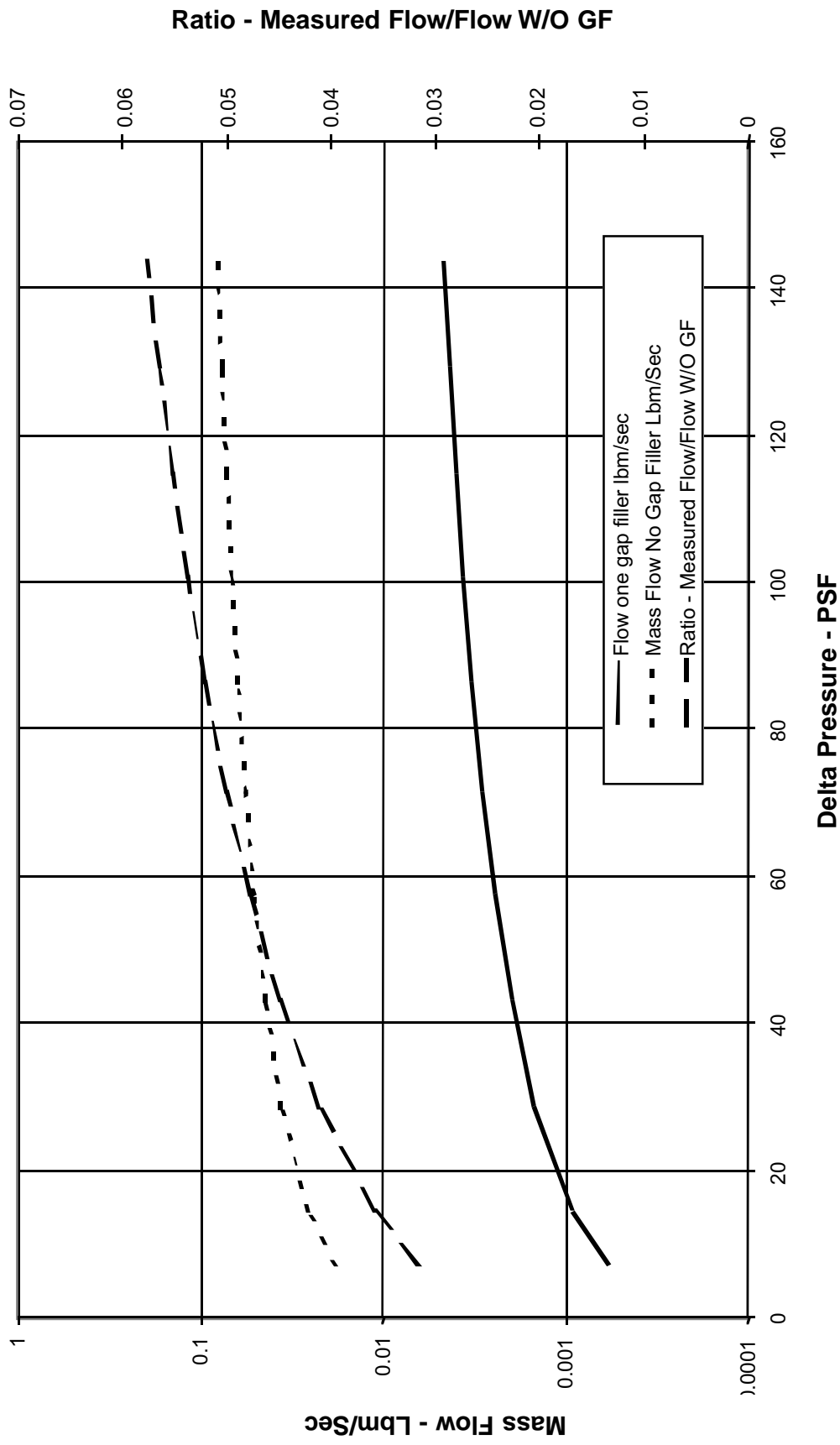
X-38 Rudder/Fin Seal Test

- ❖ Test Conducted at Glenn Research Center (B. Steinetz/P. Dunlap) to Establish:
 - Flow Characteristics of Seal
 - Seal Compression Forces
 - Seal Resiliency
 - Temperature Effects

- ❖ Test Results Indicate:
 - Seal Effective in Blocking Flow Thru Gap
 - Less Than 6% Leakage
 - 20% Seal Compression Results:
 - Unit load of 2.01 lb/in² on rub contact
 - Pre-load of 4.4 lb/in² based on contact seal width of 0.455 in



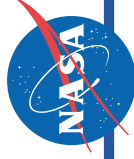
Mass Flow Versus Delta Pressure - Single Gap Filler



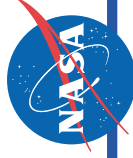
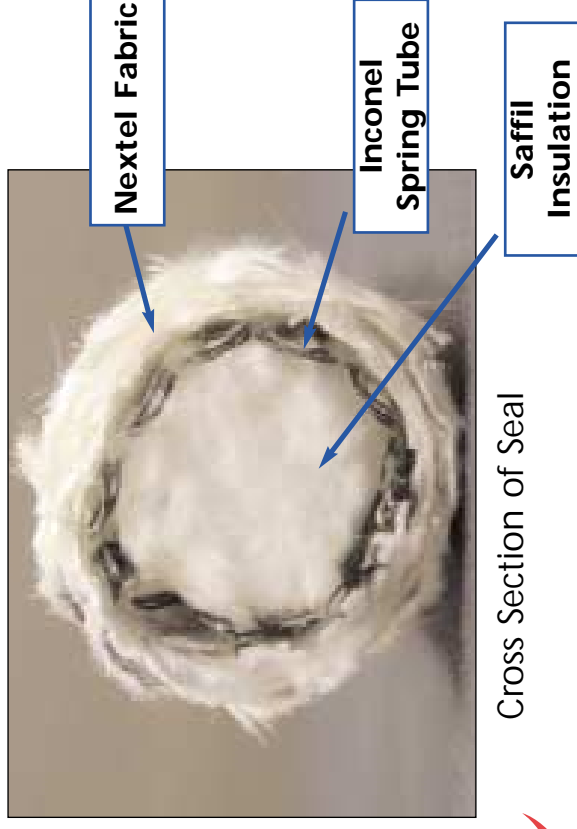
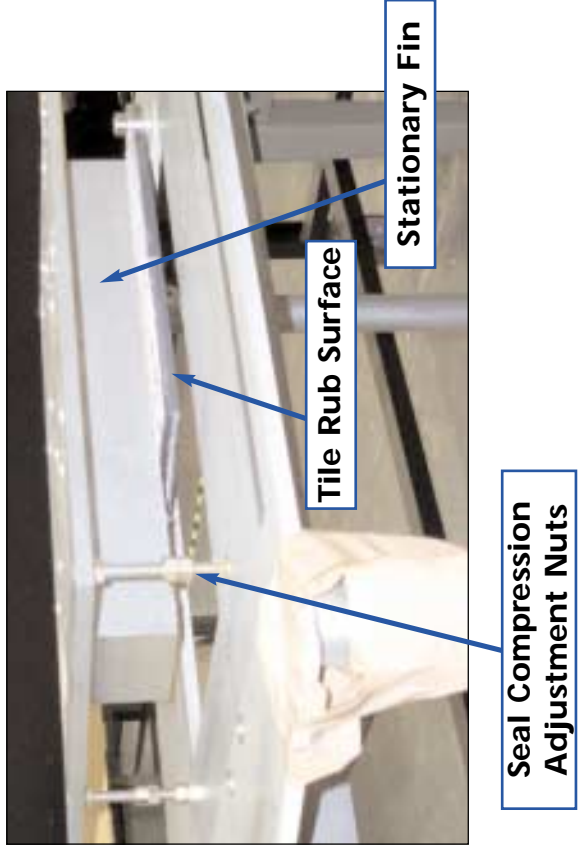
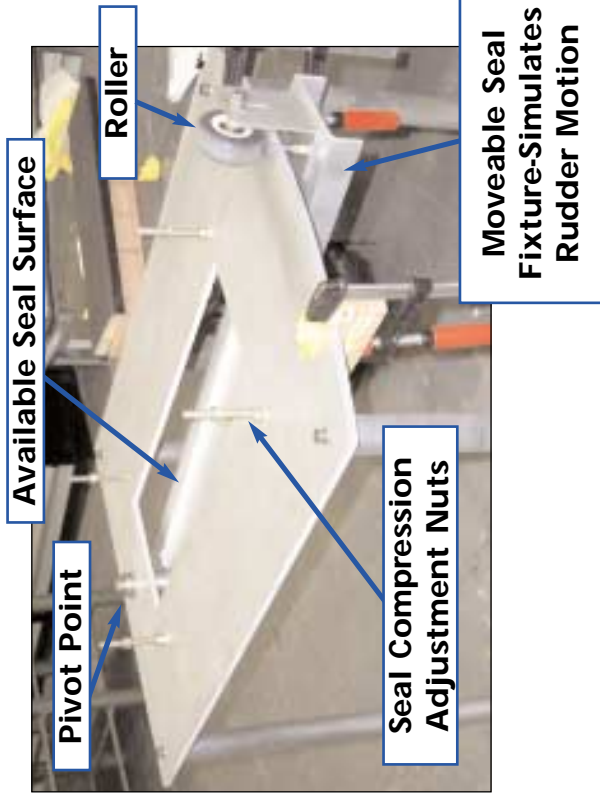
X-38 Rudder/Fin Rub Test

Objective:

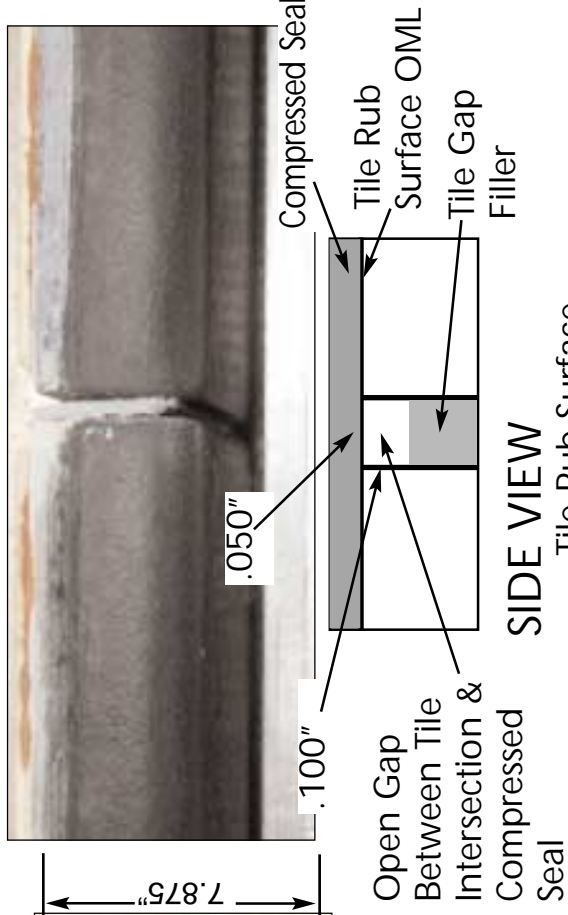
- Evaluate Normal Force of Compressed Spring Tube Seal on Sealing Surface
- Determine Frictional Force as Compressed Spring is Moved Over Sealing Surface
- Visually Observe Deformation and Springback Characteristics of Seal as it Engages/Disengages Sealing Surface
- Investigate Wear Performance of Seal with Repeated Cycles



Rudder/Fin Rub Test Assembly

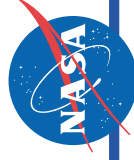


X-38 Rudder/Fin Rub Test



TOP VIEW
Northrup Grumman Surface

END VIEW
Northrup Grumman Surface



X-38 Rudder/Fin Rub Test

Results:

- Initial Test indicated that Coefficient of Friction and Torque required to Rotate Compressed Seal was Less on Northrup Grumman Black Glass Surface Than the Standard RCG/TUFI Coated AETB-8 Tile

- Northrup Grumman CMC
 - Coefficient of Friction: 0.31-0.32
 - Torque: 300-305 in-lb
- RCG/TUFI Coated AETB-8 Tile
 - Coefficient of Friction: 0.48-0.53
 - Torque: 700-800 in-lb

Cyclic Testing Conducted with Tile Rub Surface

- After 100 Cycles of Seal Engage/Disengage Local Failure of Outer Nextel Fabric Associated with Rough Tile
- Removed Rough Tile, Sanded Remaining Two Tiles to Decrease Roughness and Continued Testing Cycle

Continued.....

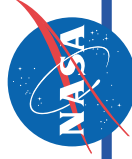


X-38 Rudder/Fin Rub Test

- After 500 Cycles with Smooth Tiles
 - Seal Shows Minor Evidence of Wear (broken fibers)
- After 1000 Cycles with Smooth Tiles
 - Outer Fabric of Seal Failed and Spring Tube was Visible
 - Torque Required to Engage/Disengage Seal was 380 in-lb

Post Test Roughness Measurements

- TUF1/RCG Tile (Rough)
 - 515-574 Micro-Inch RMS
- TUF1/RCG Tile (Sanded)
 - 303-331 Micro-Inch RMS
 - 91 Micro-Inch RMS (Super-Smooth Area)
- Orbiter RCG Baseline Tile
 - 196 Micro-Inch RMS
- Northrop Grumman
 - 282-392 Micro-inch RMS



X-38 Rudder/Fin Rub Test Results



END VIEW

Seal After 100 Cycles with Rough Tile



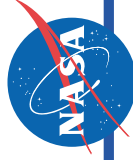
SIDE VIEW



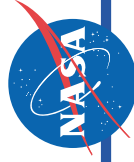
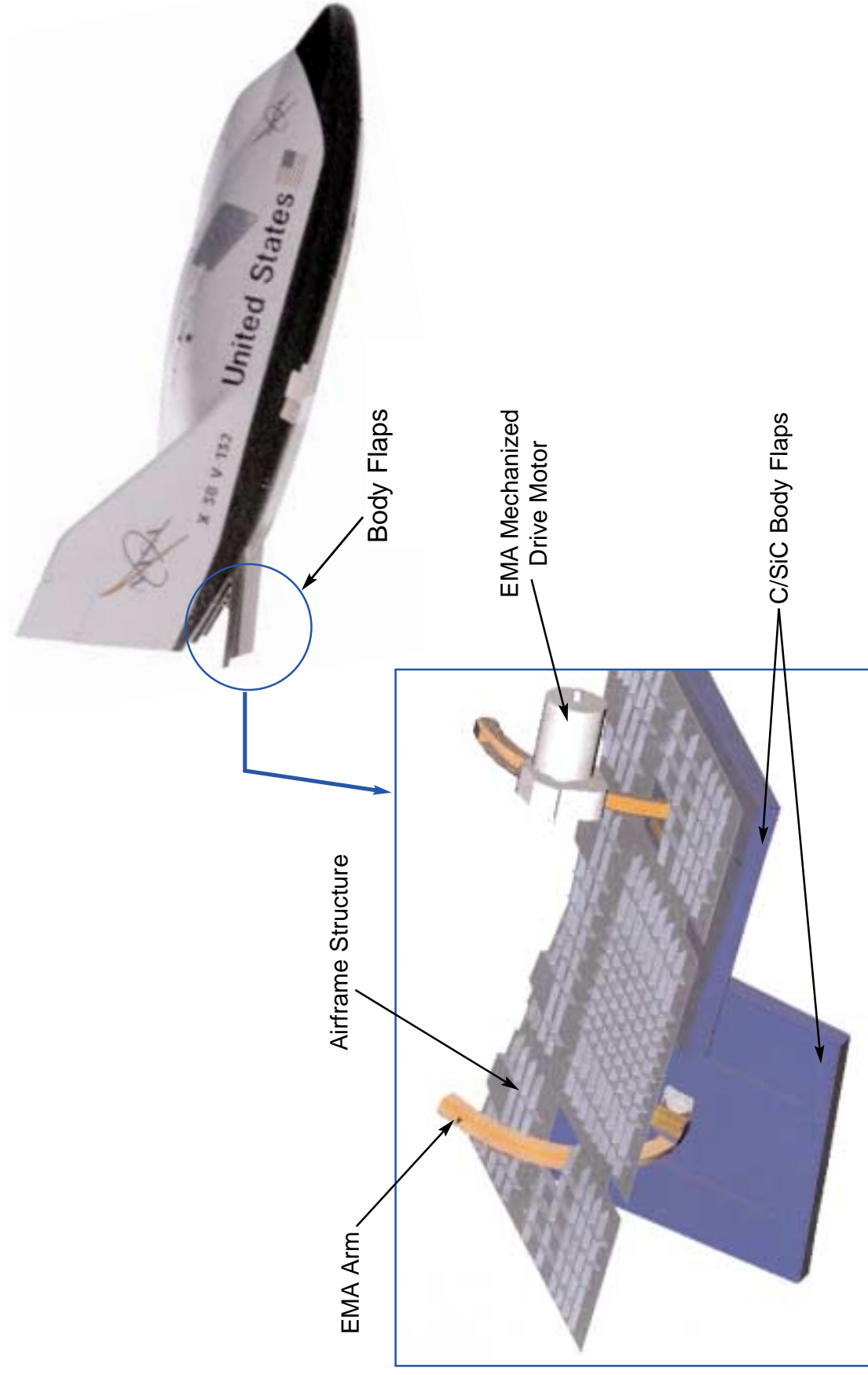
Tile Surface After Sanding



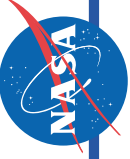
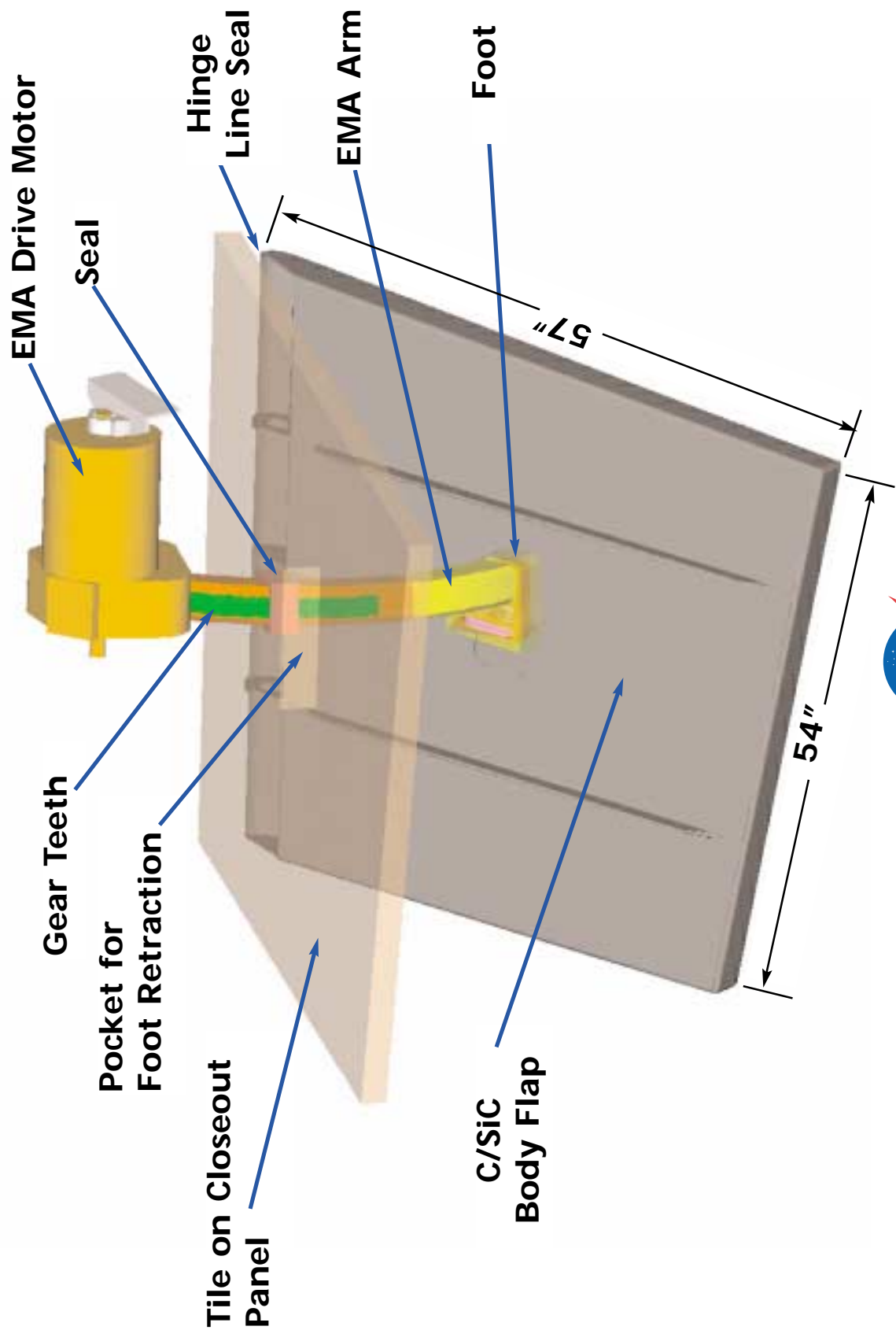
Seal After 1000 Cycles with Smooth Tile



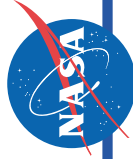
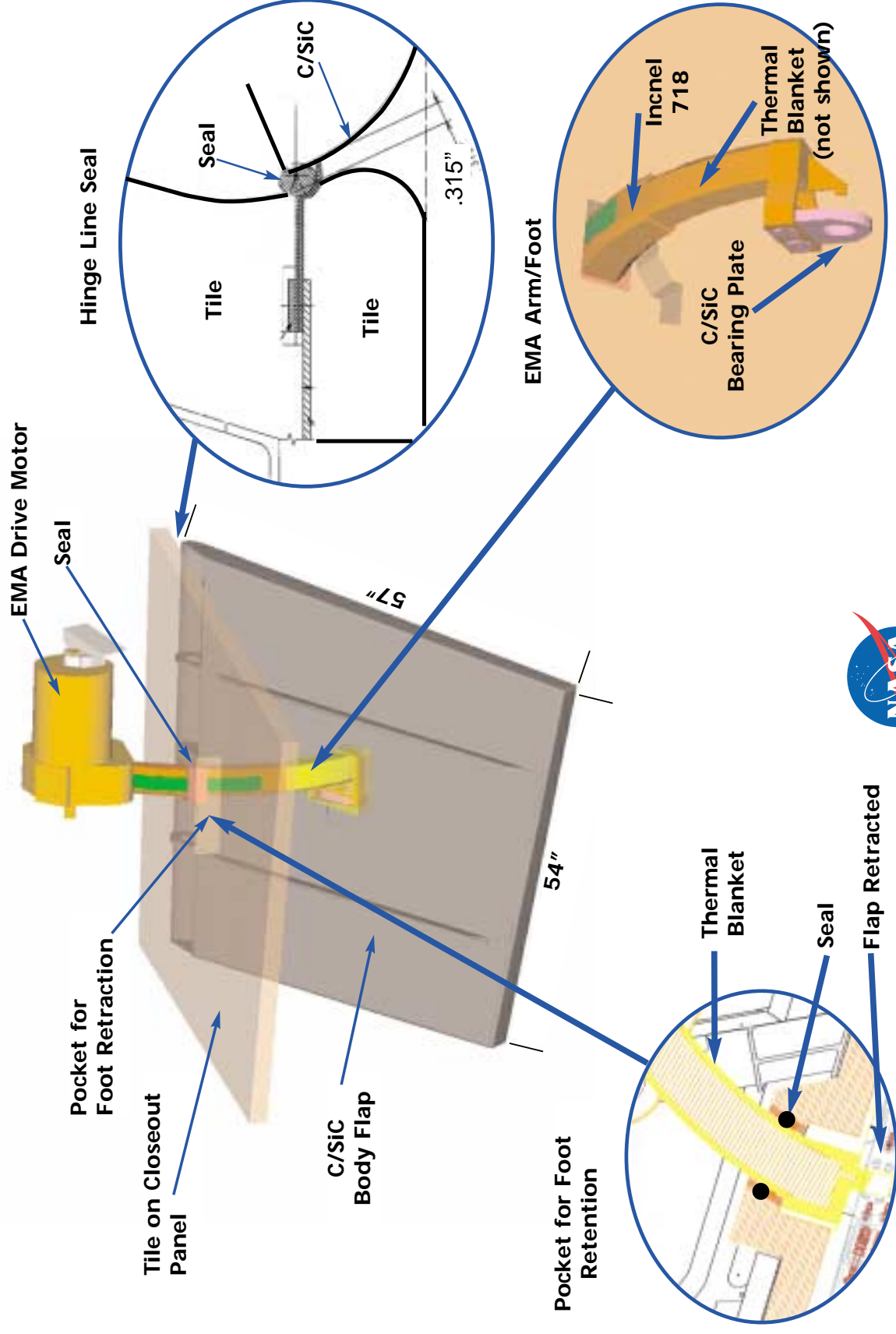
X-38 Body Flap Assembly



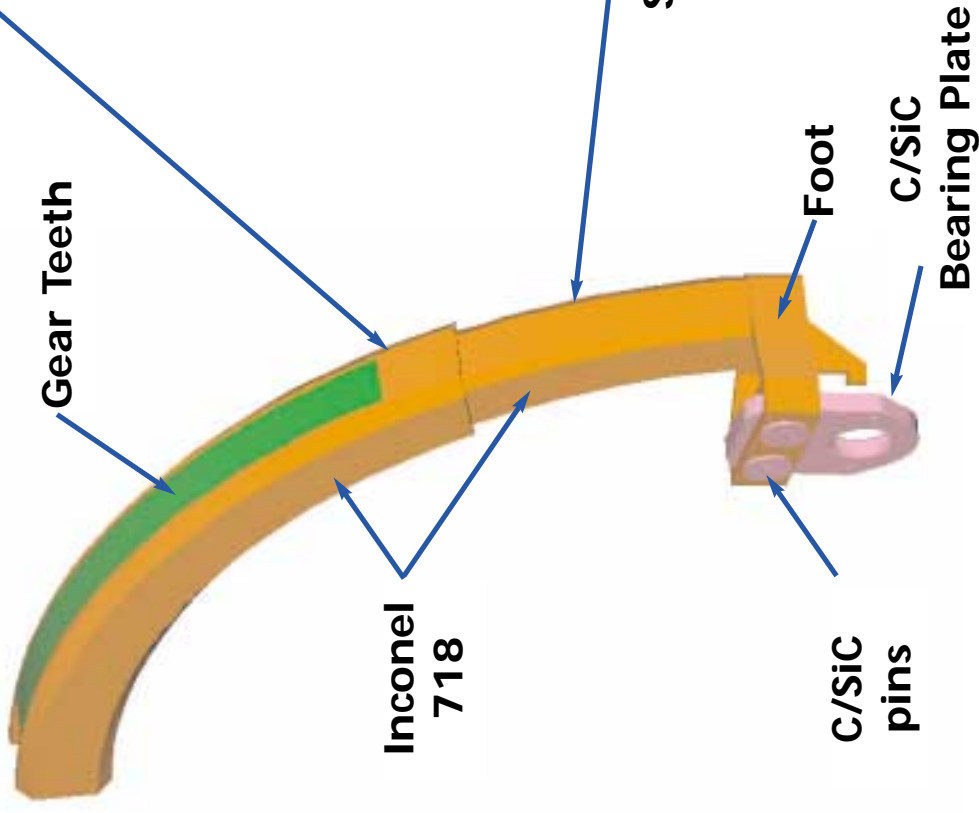
Baseline X-38 Bodyflap Seal Design



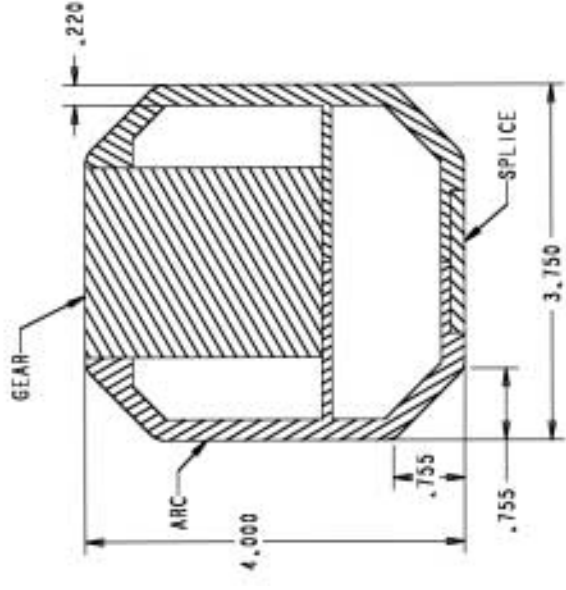
EMA Arm with Thermal Shield



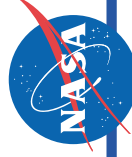
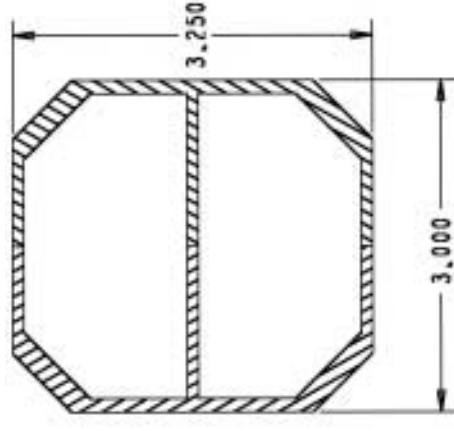
EMA Arm Without Thermal Shield



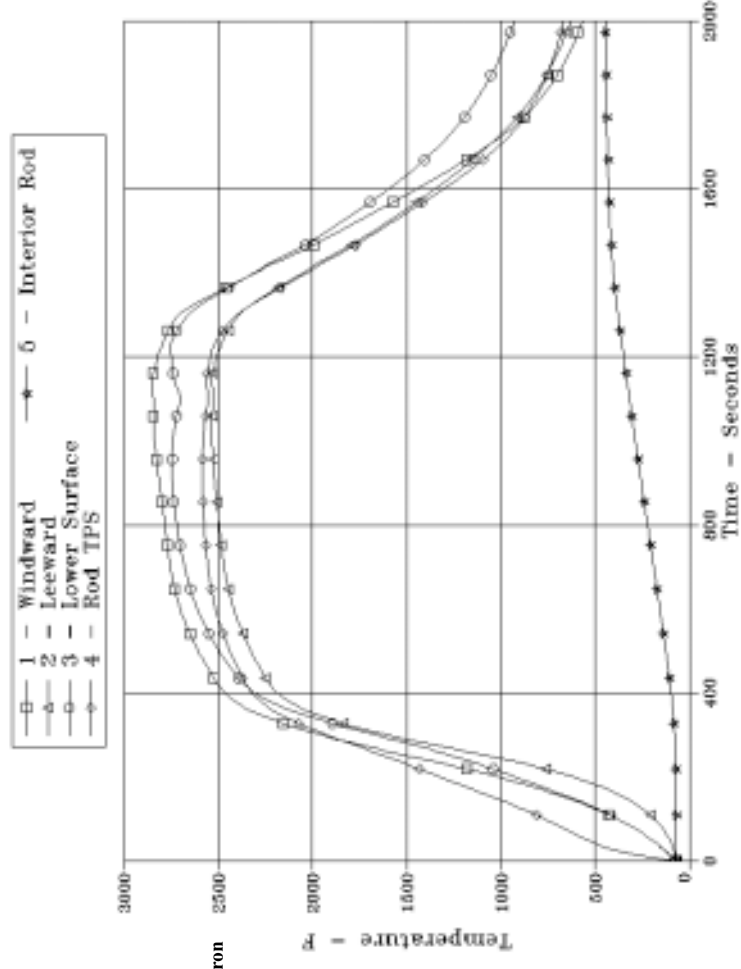
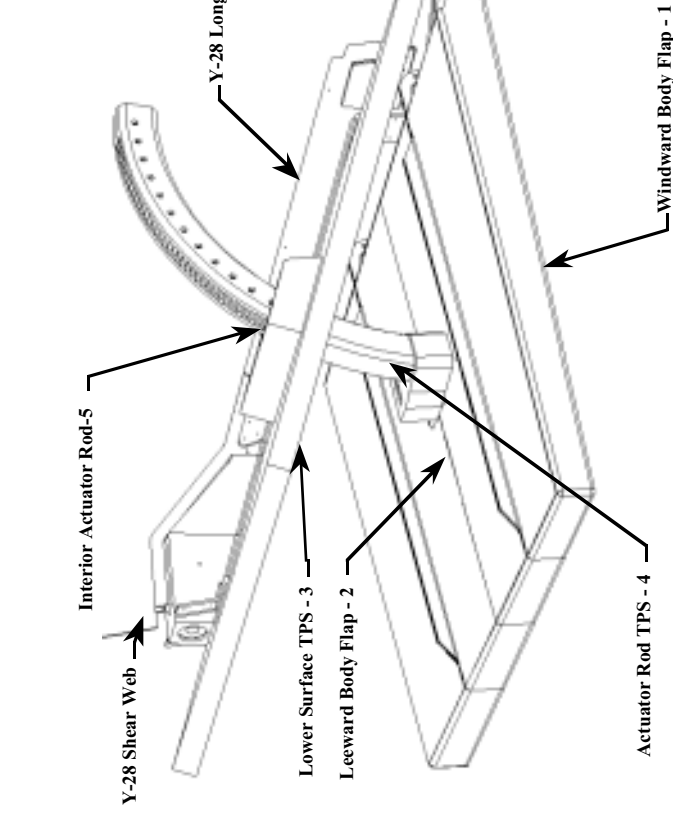
Section A A



Section B B



Body Flap Cavity Thermal Response



Body Flap EMA Arm Thermal Response

Structure

Foot/Arc: Inconel 718

Teeth: Stainless Steel 17-4 PH

TPS

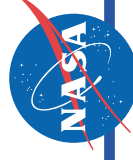
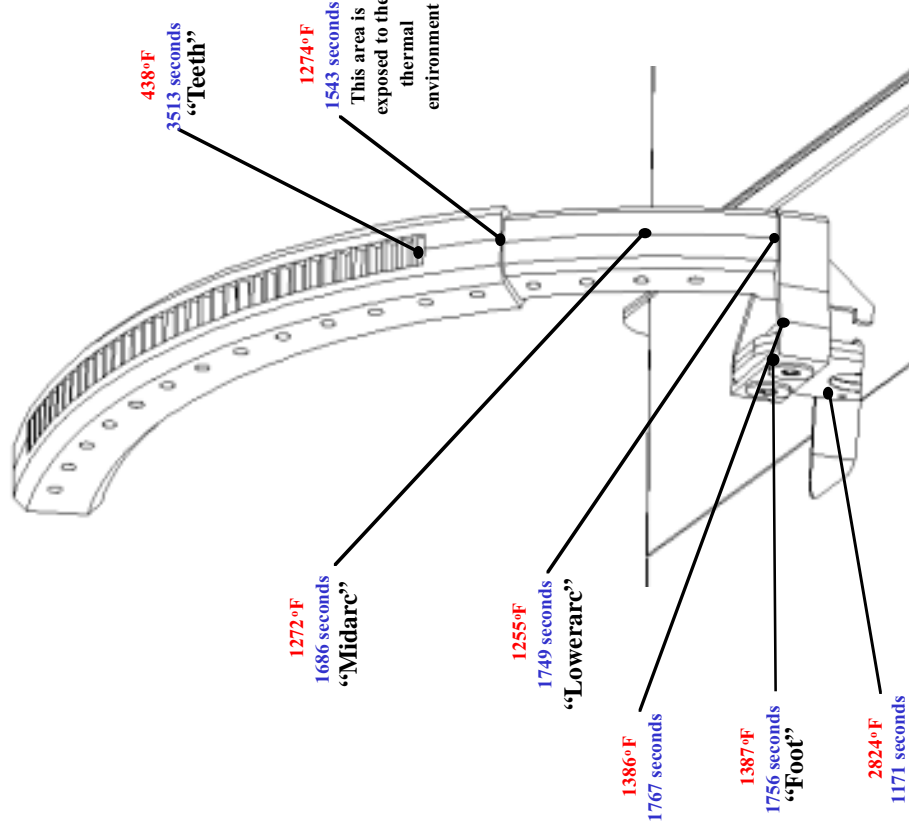
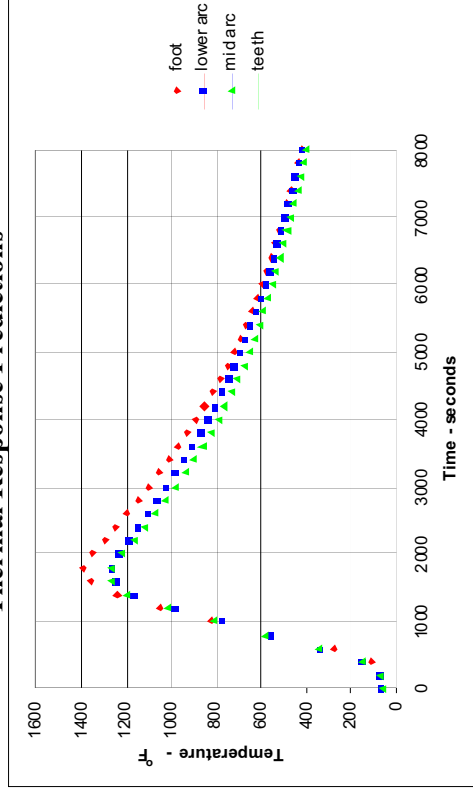
1/2" thick modified HT AFRSI Blanket
(0.54" total thickness)

Heating Environment

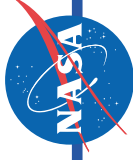
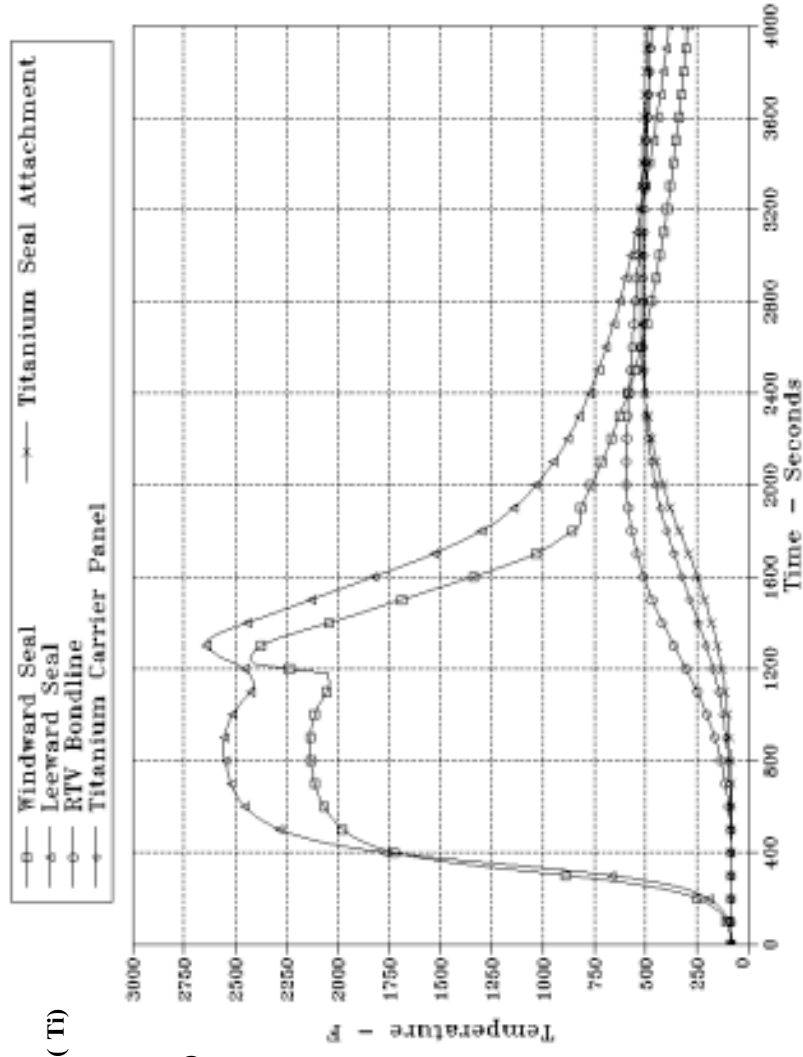
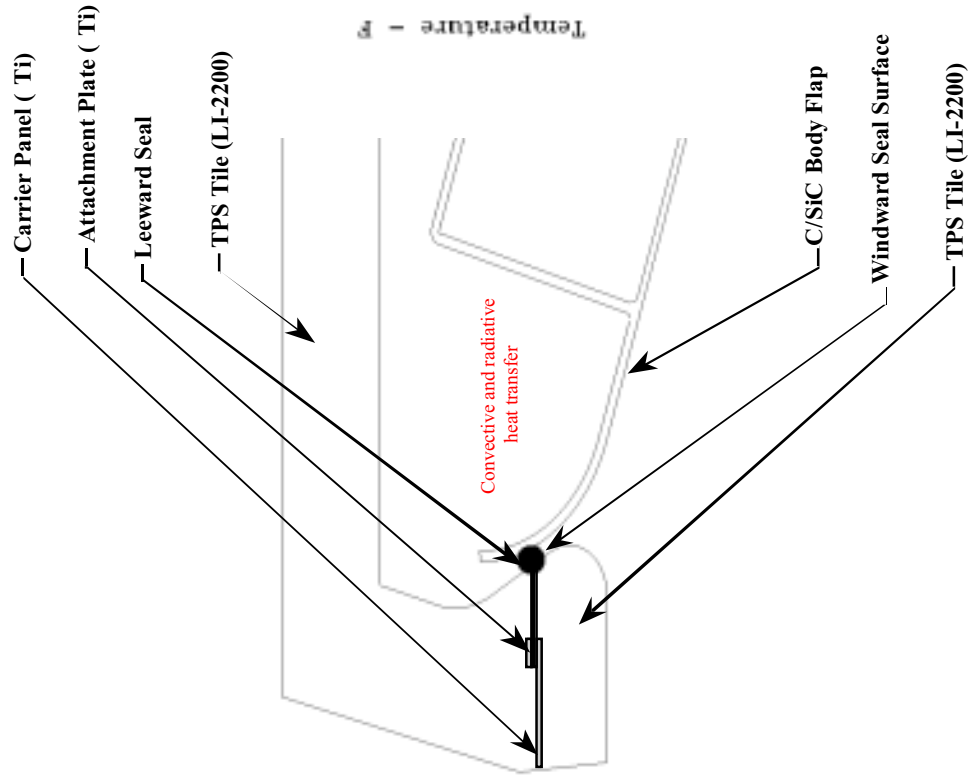
1.0 uncertainty factor applied to all heating

25° flap deflection angle

Thermal Response Predictions

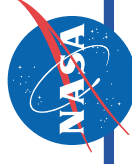


Body Flap Hinge Line Seal Thermal Response



Summary

- ❖ Glenn Research Center Spring Tube Seal Test Established
 - Flow Characteristics
 - Compressed Seal Unit Load/Contact Pressure
 - Resilency
 - Effect of Temperature
- ❖ JSC Rudder/Fin Rub Test
 - Validated Seal Scissor Action Design
 - Provided Coefficients of Friction/Operational Torque
 - Preliminary Coefficient of Friction
 - Engaging/Disengaging Torque Valves
 - Wear Characteristics of Seal
 - Requirement to Fill Open Gap Between Tiles for a Tile Rub Surface Design
- ❖ Future Tests
 - Flow Characteristics
 - Seal Compression Levels of 10% and 0%
 - Seal Degraded from Rub Tests
 - Rub Tests
 - Smooth Tile Rub Surface
 - Redesigned Tile Gap



NASA Facts

National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas 77058

International Space Station

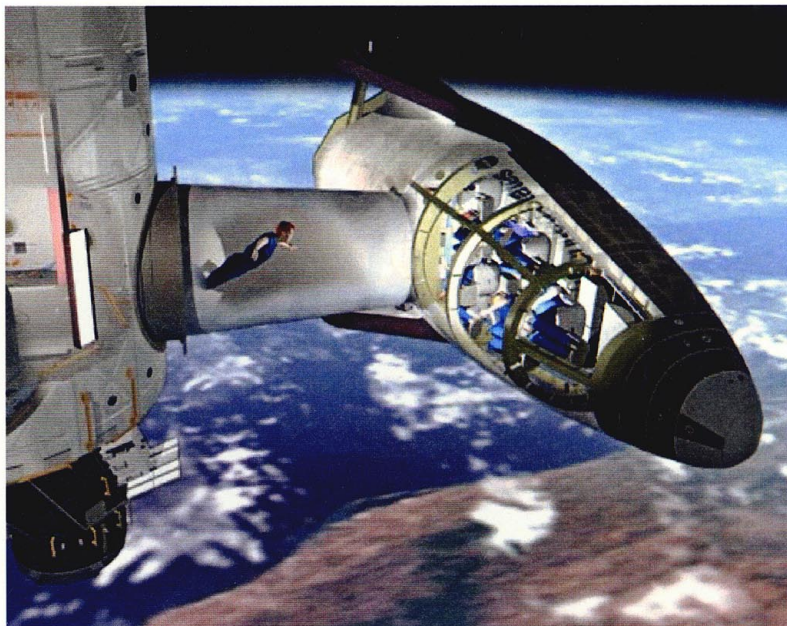


June 2000

The X-38: Low-Cost, High-Tech Space Rescue

A Reliable Lifeboat, Ambulance for the International Space Station

With technologies that blaze a trail for future human spacecraft, NASA's X-38 project is developing -- at an unprecedented low cost -- a prototype rescue vehicle to provide astronauts on the International Space Station an immediate return home in an emergency.



An innovative combination of a shape first tested in the 1970s and today's latest aerospace technology,

An X-38-derived rescue vehicle at the International Space Station. the X-38 already is flying in the actual conditions in which it must perform. Since 1997, increasingly complex, unpowered atmospheric test flights of the X-38 have been under way at the Dryden Flight Research Center in California. An unpowered X-38 space test vehicle, now under construction at the Johnson Space Center in Houston, will fly aboard the Space Shuttle in 2002 and descend to a landing independently. The X-38 is designed to fit the unique needs of a space station "lifeboat" -- long-term, maintenance-free reliability that is always in "turn-key" condition, ready to provide the entire station crew a quick, safe trip home under any circumstance.

In addition to contributions from commercial companies and NASA centers coast-to-coast, international space agencies are participating with the United States in the X-38's development. Contributions to the X-38 are being made by Germany, Belgium, Italy, Netherlands, France, Spain, Sweden and Switzerland and 22 companies throughout Europe.

Pushing the Edge: *Something New, Something Old*

The X-38 couples a proven shape, taken largely from a 1970s' Air Force project called the X-24A, with dozens of new technologies -- the world's largest parafoil parachute; the first all-electric spacecraft controls; flight software developed in a quarter of the time required for past spacecraft; laser-initiated explosive mechanisms for deploying parachutes; and global positioning system-based navigation.

The crew rescue vehicle on the International Space Station will have to be capable of a maintenance-free reliability in orbit never before achieved by a human spacecraft -- an ability to remain attached to the station for up to three years, all the while ready to depart in under three minutes, if needed. After leaving the station, it must be capable of returning a crew home in less than five hours, regardless of bad weather at some landing sites or the station's position when it departs. With medical equipment aboard, the emergency spacecraft will be both a "space ambulance" and a "space lifeboat." And capable of holding up to seven crew members, the rescue craft must have as high a passenger capacity as the space station.

The X-38 turns to the latest technology to meet these demands. Electrically powered spacecraft controls -- rather than maintenance-intensive hydraulic systems more commonly used by today's aircraft and the Space Shuttle -- drastically reduce the X-38's complexity and risks. By using a parafoil for its final descent, the X-38 does not need a long runway at the landing site, opening up many more options around the world as potential sites for a crew's emergency trip home. Laser-fired explosives eliminate a risk that stray electromagnetic interference during the years a rescue vehicle must spend in space could inadvertently cause a malfunction.



Now and Then: Above, the second X-38 test vehicle in free flight above Edwards Air Force Base, CA, in July 1999. Below, Air Force Major Cecil Powell in front of the X-24A in 1971. The X-38 combines a lifting body shape taken largely from the X-24A research with today's cutting-edge technologies.



Low-Maintenance Reliability: A Safe Trip Home in Minutes

Mission Scenario -- Because of illness, a station emergency, or a lack of available transportation, the International Space Station crew enters an X-38 rescue craft and undocks -- in less than three minutes, if necessary, or within 30 minutes under less pressing circumstances. Ground control provides landing site information, or, if needed, the entire descent could be performed independent of ground communications. Within three hours, the engines are fired to deorbit, and the deorbit module is then jettisoned. The rescue vehicle enters the atmosphere at an altitude of about 80 miles, traveling 18,000 miles per hour, half a world away from touchdown. As it descends, the wingless craft generates lift with its body and maneuvers to fly to the landing site. As air pressure increases, body flaps and rudders steer. At 23,000 feet, an 80-foot diameter drogue parachute deploys. As the craft stabilizes, the giant main parafoil begins its deployment and the drogue is cut away. In five stages to ensure a gentle descent, the parafoil slowly opens. Winches pull on lines to steer the parafoil, in the same way a skydiver steers, to the landing site. Landing skids deploy and the craft touches down, dropping at less than five miles an hour with a forward speed of about 40 miles per hour.

X-38 By The Numbers

Crew Rescue Vehicle

Length:	30 feet
Width:	14.5 feet
Cabin:	417 cubic feet
Mass:	24,000 pounds
Crew size:	7 maximum
Mission duration:	Up to 3 years
Launch time:	As low as 3 minutes

Deorbit Propulsion System

Length:	6 feet
Width:	15.5 feet
Mass:	6,000 pounds

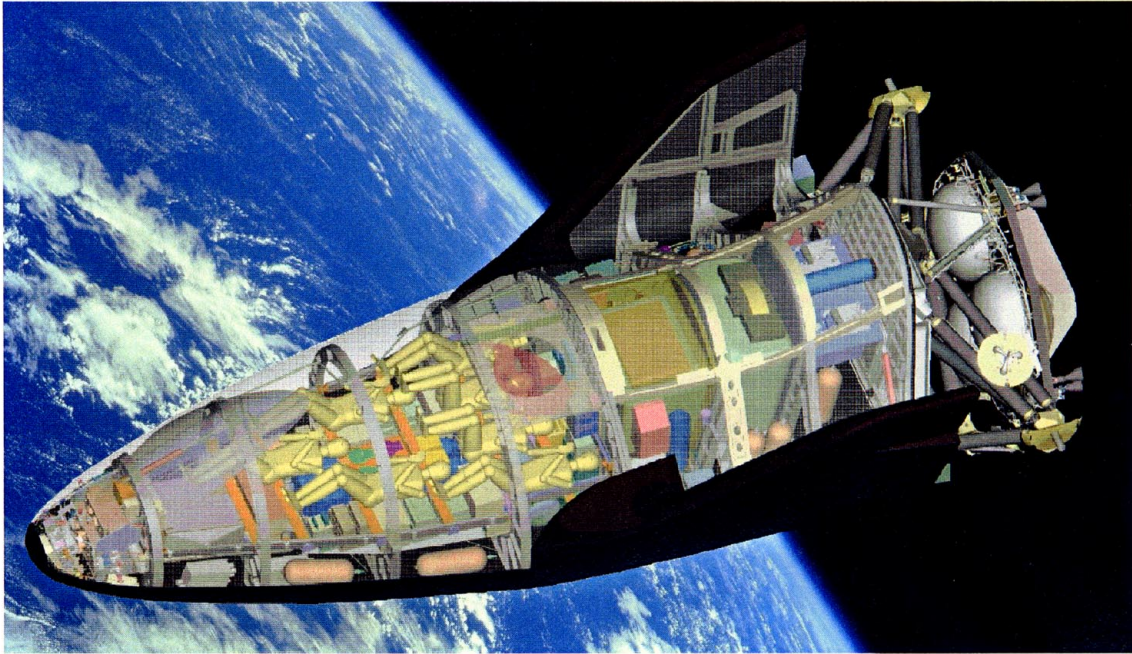
Parafoil

Area:	7,500 square feet
Span:	143 feet
Deploy altitude:	23,000 feet



A unique parafoil system guides the X-38 to touchdown at less than 40 miles per hour.

X-38 Technology: *Expanding the Envelope of Spacecraft Design*



- **Electromechanical Actuators:** Small electric motors that weigh only 10 pounds -- yet are powerful enough to move with six tons of force in a fraction of a second -- replace complicated conventional hydraulic systems to power the X-38's flaps and rudders. Hydraulic systems account for up to 25 percent of the annual maintenance on commercial aircraft, and the electrical actuators on the X-38 serve as a forerunner for a technology that has the potential to make flight simpler and safer not only in space but also on Earth.
- **Laser-Initiated Pyrotechnics:** Never before used on a human spacecraft, the explosive charges that deploy the X-38's parachutes are fired using a system of fiber optics and lasers. Using light instead of electricity simplifies the system and reduces the potential for electromagnetic interference during the extended stays the X-38 will experience in orbit.
- **Landing Skids:** Rather than temperature-sensitive tires, the X-38 uses simple skids as landing gear, eliminating the need to watch inflation pressures, brakes, or other complex mechanisms during the years it spends in space.
- **Navigation:** The X-38 uses compact Global Positioning System and electronics technology for its primary navigation system -- never before used as the primary navigation equipment on a human spacecraft -- rather than the complex mechanical navigation platforms used as the primary system aboard the Space Shuttle. The GPS navigation system designed for the X-38 already has been flight-tested as a payload aboard the Space Shuttle.

- **Lifting Body:** The X-38's special lifting body shape -- a shape that creates lift so the craft can fly even though it has no wings -- is a modified version of a shape tested by the Air Force in the late 1960s and 1970s. The Air Force's previous testing has reduced the costs associated with the X-38. The lifting body shape gives the X-38 the capability to fly to a landing site during its descent, increasing the number of possible landing sites. Two movable fins and body flaps provide steering for the spacecraft as it descends into the atmosphere.

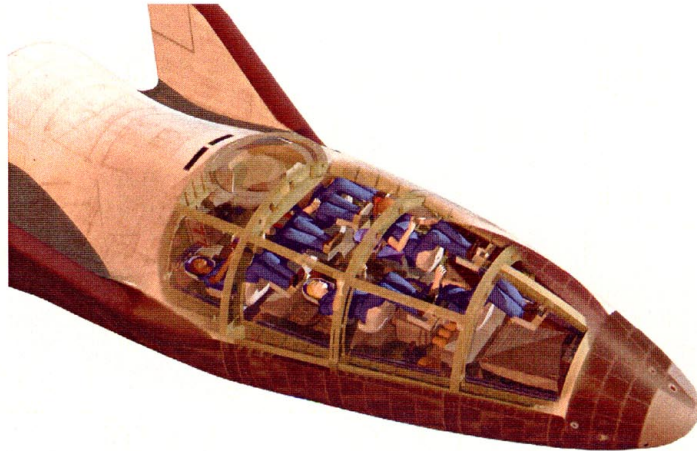
- **Parafoil:** A 7,500 square-foot parafoil, the world's largest, allows the X-38 to have great flexibility to get a crew back to Earth quickly with dozens of potential landing sites around the world, eliminating the need for a miles-long runway to accommodate high-speed landings similar to the Space Shuttle. Using the parafoil to glide to its final descent, the X-38 touches down at under 40 miles per hour and skids to a stop in only 150 feet. The giant X-38 parafoil, almost one and a half times as large as the wings of a 747 jumbo jet, may be a technology that finds other uses, including future spacecraft and uses on Earth that require precise landings, such as airdrops of humanitarian aid.



7,500 square-foot parafoil test

- **Life Support:** For reliability, the X-38's life support system uses proven, simple technologies: Lithium batteries already used on many Shuttle-deployed satellites provide electricity. Active cooling of the cabin and electronics is provided by a sublimator technology first used on the Apollo lunar lander. Carbon dioxide is scrubbed from the cabin air using lithium hydroxide canisters that have been used virtually problem-free on all human spacecraft. The fire extinguishing system uses technology commonly found on advanced fighter aircraft. And the communications system is identical to technologies used on most NASA satellites. As a custom-built rescue craft, the X-38 can provide a normal sea-level pressure atmosphere for seven crew members for at least nine hours, twice as long as is required for a worst-case return to Earth.

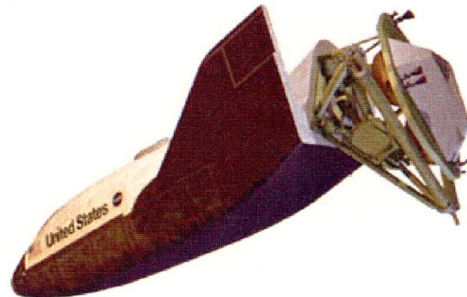
- **Crew Cabin:** The station "lifeboat" will hold a crew of seven -- the entire crew of the station, ensuring no one is left behind in an emergency -- and be capable of returning to Earth automatically. The crew will be able to take over manual control of some functions, such as



selecting a landing site and steering the parafoil during final descent. The crew will land in a supine position and be subjected to minimal force to protect members that may be sick, injured or deconditioned from long exposure to weightlessness. The crew can monitor the operation of an X-38 rescue vehicle and manually take over using color display screens and controls. The cabin is windowless; exterior views are provided to the crew by television cameras.

- **Thermal Protection System:** The X-38 is protected from the almost 3,000 degrees Fahrenheit experienced during entry into the atmosphere by the same thermal tiles and blankets that protect the Space Shuttle. But, underneath the insulation, the outer skin of the X-38 uses lightweight, superstrong composite materials for the first time. The use of a composite material reduces the amount of flex in the spacecraft's skin and thus simplifies the way tiles are attached, allowing larger tiles to be used.

- **Deorbit Propulsion Module:** The only portion of the X-38 that is not reusable, the deorbit module provides the thrust and orientation control required to begin the rescue craft's descent. Designed for lightweight reliability, the module is built with composite materials, uses a single propellant and has its own set of batteries. To provide adequate backup capability, eight thrusters, each capable of producing 100 pounds of thrust, are fired for about 10 minutes to begin the X-38's descent. If any thrusters fail, the others can be fired longer and maintain a safe trip home for the crew. In addition, eight smaller thrusters, capable of 25 pounds of thrust each, provide orientation control during the deorbit firing. After the engine firings are completed, the module is jettisoned and burns up in the atmosphere.



Taking Flight: Testing That Reduces Risks and Costs

An Unprecedented Efficiency -- The X-38 project is developing a prototype rescue spacecraft for less than a tenth of the cost of past estimates for such a vehicle. Development of the X-38 through the flight of an unpowered space vehicle in 2002 is estimated to cost about \$150 million. Previous estimates for the development of other station rescue concepts have ranged as high as \$2 billion.



The first two X-38 atmospheric test vehicles, designated V-131 and V-132, during pre- and post-test checkouts and preparation at Dryden Flight Research Center, CA.

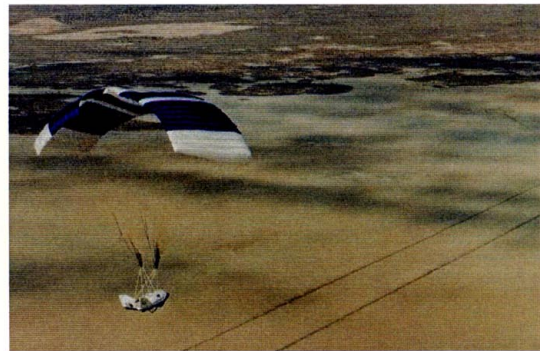
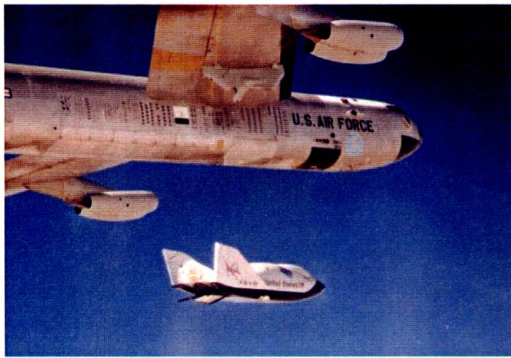
The estimated cost of the entire crew return vehicle project, from development through the construction of four operational spacecraft, ground simulators, spare parts, landing site support facilities and control center capabilities is less than \$1 billion, less than half of the cost to manufacture a single Space Shuttle orbiter. To keep costs low, the X-38's innovative, high-tech development approach uses computerized design, automated fabrication and computerized, laser inspection of many components for the space test vehicle now under construction at the Johnson Space Center in Houston. Rather than seeking early commercial bids on the spacecraft's design, in-depth development and testing of the X-38 is being done largely "in-house" by NASA civil servants. The unusual approach allows NASA personnel to gain a superior understanding of the design, costs, tests, and risks associated with the spacecraft before seeking commercial bids.



Put to the Test -- Testing of the X-38 has been under way since 1995, when over 300 subscale flight tests of the parafoil and lifting body began. Large-scale flight testing began in 1997 when the first X-38 atmospheric test vehicle was flown on "captive carry" tests under the wing of a B-52 aircraft at NASA's Dryden Flight Research Center, California. The same vehicle flew in the first free flight tests in 1998. A second, more sophisticated test vehicle first flew in March 1999 and, in March 2000,

completed a flight from 39,000 feet that intercepted the trajectory of a crew return vehicle returning from space for the first time.

At the U.S. Army's Yuma Proving Ground in Arizona, the X-38 team successfully tested the largest parafoil ever produced, 7,500 square feet, in February 2000. Flight tests that increase in complexity and altitude will continue through at least 2001 with two more X-38 atmospheric test vehicles, leading up to the first X-38 flight in space in the spring of 2002. The X-38 space test vehicle is already under construction at the Johnson Space Center. The unpiloted space vehicle will be carried to orbit in the payload bay of the Space Shuttle, released using the Shuttle's robotic arm and then descend to landing.



Large-scale X-38 atmospheric flight tests have been under way since 1997 and will continue, increasing in complexity and altitude each time, through 2001.

A National and International Partnership -- The X-38 draws on talent and expertise coast to coast in the United States and throughout Europe. Led by NASA's Johnson Space Center in Houston, NASA facilities include: flight testing at the Dryden Flight Research Center, CA; development of the Deorbit Propulsion System at the Marshall Space Flight Center in Huntsville, AL; tile manufacturing and launch processing at the Kennedy Space Center, FL; communications equipment from the Goddard Space Flight Center, MD; wind tunnel testing at the Langley Research Center, Hampton, VA; aerothermal analysis by the Ames Research Center, CA; and electromechanical actuator consultation from the Lewis Research Center, OH. In addition, the U.S. Army provides testing support at the Yuma Proving Ground, AZ; the U.S. Air Force has provided in-flight simulation support; and Sandia National Laboratories has provided parachute systems expertise. Companies with major roles in the project include Scaled Composites, Inc., of Mojave, CA, construction of the atmospheric test vehicle aeroshells; Aerojet Gencorp of Sacramento, CA, construction of the space test vehicle's Deorbit Propulsion Module; Honeywell Space Systems, Houston, development of the flight control software; and Pioneer Aerospace, Inc., of Columbia, MS, fabrication of the parafoil. In addition, the German Space Agency and the European Space Agency are contributing to the project, involving eight countries and 22 companies throughout Europe.



X-38 space test vehicle